



## Chemistry teaching and learning: is there a future?

### The 2001 Presidential Address by Stuart W Bennett

#### Declining numbers

Major research areas in 'molecular science' are now not centred within the traditional chemistry divisions. It is areas of molecular health, biological and environmental chemistry, geochemistry and materials that are seeing the greatest advances and the greatest investment in research. The inorganic, organic and physical divisions served chemistry well during the 19th century and for a good part of the 20th century. Maybe these divisions are no longer appropriate and perhaps now they are even doing damage. Does teaching and learning of chemistry reflect today and tomorrow, rather than being an echo of the structure of the subject yesterday?



So how are students voting? In chemistry A-levels in the UK in 1992 (excluding the somewhat different qualifications in Scotland) there were about 42 600 candidates, and by 2001 that number had fallen by 11 per cent to around 38 000 candidates. It is disappointing that there has been a fall-off but it is perhaps not entirely surprising considering the range of 'new' subjects on offer. Sadly this fall of 11 per cent must be set against the 37 per cent rise in numbers taking A-levels in this period from 1992 to 2001. The number of chemistry A-level candidates based on the total change for all A-levels shows a fall of 35 per cent. Clearly, the fall in the popularity of chemistry with students in the 16-18 year range is significant. Many university chemistry departments have been struggling to fill places and several departments have been closed or amalgamated.

Is this something that should cause concern? Students are affected by a whole basket of influences including employment, image, perceived difficulty of study, many of which are outside the control of teachers. Is popularity important? It might be for teachers of chemistry whose employment depends on the numbers of students studying the subject. *The Sun* is the most popular newspaper in the UK based on sales but that says little about quality. Is chemistry influenced like almost everything else by market forces and, if so, is there any point about thinking about change at all?

#### Teaching chemistry

So how has chemistry been taught? It can be useful to compare with a completely different subject area, say history or literature. A student entering university to study literature can be given a novel to read and be quite capable of discussing that novel in a seminar a week later. Certainly the level of discussion would not be that same as that expected from a final year student but, nevertheless, it would be worthwhile and constructive. The equivalent chemistry student is not asked to carry out such an exercise. There is the view that the nature of chemistry is such that one cannot be creative and holistic until a range of tools, skills and knowledge has been assembled. In chemistry separate parts are learnt and only put together towards the end of undergraduate study in project work. Is it possible to develop a more holistic and system-based approach to the learning of chemistry? Certainly topics will need to be revisited and developed but is this a problem? How change comes is a different issue but certainly it is going to require school curricula and assessment to change, as well as changes to be made in universities.

The results of a series of surveys of first year chemistry university students, including the Open University (OU), yielded three major powerfully-held (if not entirely surprising) perceptions.

*Dynamism:* Chemistry is not seen to be alive. There is little opportunity for discussion, opinion and interpretation. It is a collection of facts and abstract ideas.

*Difficulty:* Chemistry has very specific language and symbolism. There are lots of facts and tools that you have to acquire before you can do anything exciting. Undergraduate workloads for chemistry (particularly with practical work) seem to be much greater than for many others.

*Image:* Chemistry is perceived by the public in a pejorative context being related to environmental damage and danger. It is less readily identified with improvements to the quality of life in areas such as medicine and materials.

It would be very easy to say that an individual teacher has minimal control of any of the three areas of concern identified by students. However, this would be an abrogation of collective responsibility. It is not suggested that the road of populism is chosen for its own sake, but are students being provided with the best experience?

Is it necessary for the student to spend so much time in the laboratory, and is that time appropriately spent? The supporting argument that the product is the professional chemist is suspect in that under 30 per cent of chemistry majors go on to use chemistry directly in employment. Is a spiral approach in teaching used often enough, where an area is introduced and revisited over time, gradually refining it? The basic idea of drugs and receptor sites is quite simple, but why wait until the student has all the detailed information before introducing the basic idea of how such drugs operate? Maybe the image of chemistry (at least in the eyes of students) might change if more exemplars were chosen where chemistry had benefited humanity, rather than those where there had been chemical damage to the environment.

The pleasing aspect of chemistry teaching is that there are changes underway, but for many, these changes are not happening quickly enough. A major area where radical change is urgently required is simply with the sheer quantity of material in chemistry curricula. Chemists are rightly very good at introducing new areas of research into undergraduate courses, but are particularly inept at taking things out. The result is an overloaded experience for the student where there is no time for creative thinking, surely a quality that should be developed by all students.

### **Assessment**

Whether teachers like it or not, assessment is probably the major driver for students in higher education. If a concept, skill or knowledge chunk is deemed to be examinable, then it is given high priority in the learning strategy of the student. This may seem to be a stunningly obvious conclusion, but are the implications fully recognised and actioned by all educators? There are then two possibilities, either to change this culture of assessment-driven learning, or to use it as an opportunity to improve learning. Over the last decade and more, there have been many laudable and reasonably successful programmes that have introduced context-based learning, problem solving approaches and holistic perspectives. However, they have not been successful in removing assessment as the major learning driver.

### **Learning outcomes**

Assessment is a means of testing whether learning outcomes have been achieved. The Quality Assurance Agency defines learning outcomes as 'statements that predict what learners have gained as a result of learning' and the '...achievement of which a student should be able to demonstrate'. So providing learning outcomes are defined competently, students should be motivated to focus on the skills and knowledge that the course is expected to deliver, and have a clear idea of the expected outcomes and their assessment. However, the competent definition of learning outcomes must include information about assessment criteria and mode. The Chemistry Benchmark Statement identifies a range of assessment media. The list includes formal examinations, laboratory reports, problem solving exercises, oral presentations and the planning, conduct and reporting of project work. In addition, essay assignments, portfolios of chemical activities undertaken, literature surveys and evaluations, collaborative project work, preparation and displays of posters relating to project work and reports on external placement are all included. So there is no shortage of recognised assessment media within the chemistry establishment.

All institutions use a subset of these assessment media but how often is there a cross check made to ensure that all outcomes are tested? The underlying questions are 'Are we teaching what we think we are teaching?' and 'Are students learning what we think they are learning?' Learning outcomes are an integral part of course design and certainly not an 'add on'.

### The examination

Major differences between formal examinations and coursework draw attention to the strength and weaknesses of these media in terms of testing different learning outcomes. For example, the examination is not good for tasks which include retrieval, processing and using data and other information in the context supporting an hypothesis.

#### Examination

- can be sure of whose work it is
- closed system
- time limited

#### Course work

- not sure of extent of individual student's contribution
- open system
- opportunity for team work

Whilst recognising that some learning outcomes are inappropriate for testing by examination, a detailed study of first-year university, chemistry-based examination papers and the relationship of questions to learning outcomes has been carried out. It was only possible to do this where course (or module) learning outcomes had been defined, and the subset tested by examination identified. The co-operation of twenty-two UK universities, six in the USA and four Australian who supplied a total of eighty-four examination papers, together with related learning outcomes, is gratefully acknowledged

The first task was to assign where possible the appropriate learning outcomes to the individual questions on a typical, carefully thought out, example. (See Fig. 1)

Figure 1 OUTCOME	SECTION A 2/4				SECTION B 3/5				
	1	2	3	4	5	6	7	8	9
A	Y	Y		Y					
B			Y			Y		Y	
C		Y			Y		Y		Y
D									
E				Y					
F					Y	Y			Y
G									Y

This simple analysis indicates that outcome D is not tested at all and outcomes E and G are tested in just one question. The other outcomes are tested in three questions, except for outcome C that is covered by four questions.

However, students are not asked to attempt all nine questions. A student attempts Questions 1 and 3, and Questions 5, 6 and 8. How does the analysis look now? (See Fig 2)

A rather less satisfactory pattern now emerges. Although outcomes B and F are tested in three and two questions respectively and A and C are tested in one question each, three learning outcomes, D, E and G, are not tested at all.

In addition, threshold pass marks in examinations mainly fall in the range 40-45 per cent, so a student could achieve a pass with under 50 per cent achievement on four of the seven learning outcomes. One might be reluctant to fly if this were the case for the assessment of pilots! The point is how the claim (*This examinations tests learning outcomes...*) is translated into what the 'successful' student has actually achieved.

The main findings from these simple analyses of examination papers are that:

- there is a mismatch between outcomes claimed and outcomes tested;
- some outcomes are tested several times in the same paper and some omitted, made worse where the paper allows a choice of question;
- in the worst cases, students are able to achieve a pass grade with less than 20 per cent of the learning outcomes fully achieved;
- questions that are easy to set and mark tend to predominate.

### Problem questions

Many of the calculation-type questions masquerading under the problem solving banner are of the type: calculate the mass of sulfur dioxide produced by burning 1.00 tonne of coal containing 0.700 per cent by mass of sulfur. Certainly this type of question does test a range of skills and knowledge but it is not a *problem*.

The answer is obtained by applying a simple, standard algorithm: find the mass of sulfur, convert to moles, use in a balanced equation to find amount of sulfur dioxide then use relative molecular

mass of sulfur dioxide to find the mass of sulfur dioxide. Problem types have been categorised using parameters, and this is a Type 1 'problem' - the input data are given, the method is familiar and the output is defined. The 'problems' in the table become more problem-like and less exercise-like further down the table. (See Fig. 3)

Figure 2 OUTCOME	SECTION A 2/4				SECTION B 3/5				
	1	2	3	4	5	6	7	8	9
A	Y	X		X					
B			Y			Y		Y	
C		X			Y		X		X
D									
E				X					
F					Y	Y			X
G									X

The claim that the examinations test problem solving could be stretching the point with 94.6 per cent of the questions analysed being Type 1 - data given,

Type	Data	Method	Output
1	G	F	D
2	G	U	D
3	I	F	D
4	I	U	D
5	G	F	O
6	G	U	O
7	I	F	O
8	I	U	O

**G - Given**                      **I - Incomplete**  
**F - Familiar**                    **U - Unfamiliar**  
**D - Defined**                    **O - Open**

**Figure 3 Problem Types**

An example of a Type 4 problem might be 'How many amino acid residues are added per second to a human hair as it grows?' The inexperienced student might panic, but with a little thought might start confining the broad question - the input data are incomplete, the method is not immediately familiar but the output is defined by the question. In a month a hair probably grows 1-2 cm, people are familiar with roughly how often they have their hair cut. How thick is a human hair? It is certainly less than 1 mm. Would ten hairs side by side cover 1 mm or would it be rather more? So there is a range for the volume of hair produced in a month (and in one second). What is the density of hair? Probably around  $0.8\text{gcm}^{-3}$  like many organic materials, so the mass produced per second can be estimated. What is the mass of an amino acid residue? The relative molecular mass gives the number of residues per second. Thus a seemingly impossible problem is broken down into manageable parts. The answer is a staggering number of around  $10^{11}$  per second. So the slow growing hair on the macro scale is a frenzy of activity at the molecular level!

An analysis of the problems in the first-year examination papers using the Types 1-8 system gives the following results. Whilst accepting that there was an interpretive element into the type allocation of some problems, the analysis does make a major point. (See Fig. 4)

method familiar and output defined, the standard algorithm type. Other media may be better suited for the testing of problem solving, but claims should match reality.

Type	Proportion %
1	94.6
2	3.0
3	2.1
4	0.0
5	0.3
6	0.0
7	0.0
8	0.0

**Figure 4 Occurrence of problem-type questions**

#### OU students and problems

Research has been carried out into non-Type 1 problem solving in chemistry with OU students. The OU student body is diverse, and overall, there is evidence that students with recent experience of higher education study tend, at least to begin with, to perform to a higher standard than those without that experience, but would this be reflected in problem solving?

A cohort of 305 students was divided three times into categories based on the England, Wales and Northern Ireland educational qualifications. (See Figs. 5 and 6)

Group	Low	High
1	None	GCSE (any) and higher
2	None plus any GCSE	GCSE (chem) and higher
3	None plus GCSE plus GCSE (chem)	Advanced level and higher

**Figure 5 Categories of student qualifications**

Group	Low		High	
	Score/100	Standard deviation	Score/100	Standard deviation
1	63	14.0	65	13.2
2	63	12.6	62	13.7
3	66	12.2	63	13.9

**Figure 6 Student performance on Type 4 problems**

The variations are not significant statistically, the performance on Type 4 problems does not seem to be affected by prior educational qualifications. However, the initial performance of students shows significant variation on Type 1 problems with a correlation between prior educational level *and* how recent was that experience.

These data represent an initial study and the cohort is being extended. It would also be interesting to investigate whether there was a development in problem solving skills as a student progressed through the undergraduate programme.

It is hoped that this address demonstrates some areas of research in chemical education, and raises issues about chemistry teaching and learning, and where creative energies might be concentrated in the future.



### VOLUNTEERS WANTED

ChemSoc needs volunteers for the committee post of Marketing, and regional representatives for 01 (London), 03 (South-west), 05 (East Midlands), 09 (North-east), 12 (Ireland) and 13 (South-east).

If you think that you have some time to offer your society, please contact a committee member to discuss how you can be involved.

### So you know your scotch?

New method reveals the age of scotch whisky

A connoisseur's palate is no longer the accurate judge of the maturity of fine Scottish whisky. Chemists at the University of Texas at Austin have created a dye complex that reveals the age of scotch at a glance, and their work has been published in *Journal of the American Chemical Society*. Sheryl Wisker and Eric Anslyn have developed a complexing agent that reacts with compounds that accumulate in whisky as it matures in oak casks. This reaction triggers a colour change, the intensity of which denotes the whisky's stage of maturity. The method was tested on several single-malt whiskies, aged between 5 and 16 years, from the distillery on the Scottish island of Islay. The colour change correlated well with the known ages.

### STRANGE GOINGS High Noon?

The ChemSoc committee members are renowned for doing strange things in the name of chemistry and the society. Pat Wilson saw these strange antics and happened to have the camera handy.

Yes it's a caption competition for you - there is a £20 prize for the winner. Send your entry to the editors, and the committee will convene to decide the winner. Remember though that the winning entry needs to be publishable and attributable!

Old whiskies can command high prices. Dealers often validate distillers' claims of a whisky's age by measuring how much gallic acid a whisky contains. Water reacts with tannin compounds in the wood, producing gallic acid, which leaches into the whisky. The longer the spirit has been in the cask, the more gallic acid it contains. However, the level of gallic acid is not a very accurate age test. It varies with the type of wood, and how many times the cask has been used and with what the cask has previously stored.

Oak casks release several tannin-derived organic acids into the whisky. No single one provides a reliable measure of age. The new method evaluates the concentrations of several tannin acids at once. The researchers add a dye complex to the whisky. Key chemical structure features of the complexing agent are a guanidium embedded in an aminomidazolone group and two boronic acid groups. The dye is pyrocatechol violet. Organic acids in the whisky replace the dye in the complex, triggering a colour change from maroon to yellow. The intensity of the change depends upon how the dye is released, which in turn depends on tannin acid concentration in the whisky.

The same method might work for oak-aged wines, which contain similar tannin-derived organic acids. However, a complexing agent more specific to tannin-derived acids may be needed.

Reference: S.L. Wiskur & E.V. Anslyn. Using a synthetic receptor to create an optical-sensing ensemble for a class of analytes: a colorimetric assay for the ageing of scotch. *J Am Chem Soc* 2001, 123 (41), 10109-10110

John K Borchardt  
'The Alchemist' October 2001. Source: Chem-Web.com, <http://alchemist.chemweb.com>  
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## Editorial

Welcome to the first 2002 edition of TouchPaper from your new Joint Editors, and a particularly warm welcome if you are a new ChemSoc member.

So, who are we and how did we get here?

Roger works full time for the OU and for the last 25 years he has been Science Staff Tutor in R03. He's an Earth Scientist, (but is sensible enough to know that you can't do your rocks if you can't do your chemistry) specializing in sedimentary rocks and beasts (fossils to you!). Since November 2001 he has been working full-time at Walton Hall as Manager of Associate Lecturer Staff Development, whilst also retaining his commitment to the Science Faculty – he is a member of the S260 and SXR103 Course Teams with particular responsibility for the SXR103 Field Trip in Sussex. He also tutors S260 in R02.

Sue is an OU graduate and Associate Lecturer, tutoring S103 in R01 and R06, S205 in R01.

As most members will know, ChemSoc gatherings are not occasions for temperance, and in a less-than-totally-sober moment, with some of our dearest ChemSoc friends at the Great Barr Hotel the night before the 2001 AGM, we, less than seri-

ously, discussed offering ourselves as joint TouchPaper editors. The next thing we knew at the AGM the next day, was that our ramblings had been taken onboard by the Committee and we found ourselves nominated unopposed and duly elected – that'll teach us!

We know that you've read this many times before in TouchPaper, but it has to be repeated – TouchPaper is **your** newsletter and we need contributions from **you!** Please send us your news and views on matters that would be of interest to members – e.g. exhibitions, or places of interest that you've visited recently. We also want items that you have spotted of chemical interest from the press and literature, or the web, that you think are of interest to members. Please quote the source of the items that you send us.

In previous years members have watched out for pubs with chemistry-related names whilst on their travels, and have submitted them for inclusion in TouchPaper, so perhaps we could revive that column? A photo of the (what do you call the sign board thing outside pubs?) would be nice too if you could manage it. OK, we know that it's a bind, particularly if you try to do a proper job and sample the beer and food for us as well, but a word of warning! If you were at the 2001 AGM you'll recall that Roger threatened to fill TouchPaper with rocks if we don't receive articles or items from members, so over to you!

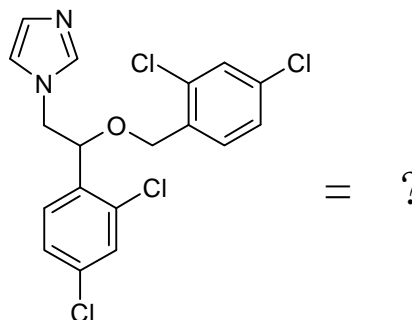
Finally, on your behalf we would like to thank Kathie Yeowell for her sterling work as Guest Editor for the last two editions, and of course the previous Editor Frank Hollis, who has produced more editions of TouchPaper than he probably cares to remember.

With best wishes for your studies, tutoring or research in 2002

Roger Beck  
Sue Whitaker

Joint Editors

## A problem for all you biochemists: what's the systematic name of this molecule?



Answer in next issue.

## The Best Kept Secret!

Have you ever rued the lack of a fourth third-level chemistry course? I know that when I was faced with finding a filler course for that final 30 points towards my degree, I rather reluctantly plumped for Living Processes (S327). However, as I found out last year, there is a viable alternative.

Quantum Mechanics (SM355) is well hidden away in the course listings amongst the physics courses, but it's billed as the 'Jewel in the Crown of the Physics Department'. So, imagine my surprise, when it very quickly became apparent that this is actually a course in Chemistry! I will admit that it is Chemistry with an awful lot of maths, but it is certainly Chemistry nonetheless.

The secret is revealed very early on, when in unit 1, the totally alien concepts (to the physicists, at least) of the 'mole', 'Avogadro's number' and 'relative atomic masses' are explained. Rather a lot of maths and some very strange looking equations later, we arrive at the next revelation...what we're evaluating is the coarse-structure of the spectroscopic energy levels of a hydrogenic (1-electron) atom. So, if you remember the pictures from S102, this shows you how to calculate them to an accuracy of one part in a million! By this point, I'm totally hooked and still the surprises of this "so-called" physics course just keep on coming.

Ever wonder just how that nucleus knows it's time to decay, well the quantum description of alpha decay reveals the answer in Unit 6. Then onwards and upwards as we are treated to a complete treatment of electron spin. This is absolutely fascinating and it soon becomes rather clear that there is somewhat more to it than just drawing arrows in the up and down direction.

Further on, there is a complete description of how the different s, p, d and f (and indeed higher!) orbitals of atoms can be calculated. The treatment of total angular momentum leads to an enhanced understanding of just what all those different quantum numbers of an electron are about. With a bit more maths and a few more scary equations, the previous accuracy of the spectroscopic energy levels is surpassed and the evaluation of the fine-structure of the hydrogen atom is accurate to 1 part in 100 000 million. Forget all that popularist nonsense about Quantum Mechanics not being able to tell you anything with any accuracy. The simple answer is that it can, and the course also explains why you can achieve such accuracy with energy levels, whilst the simultaneous measurement of

momentum and position always carries an associated uncertainty.

Then just when I think we'd finished with all the revelations the final two units of the course turn out to be on quantum chemistry. The very safe territory of the hydrogen atom is left behind, and these two units are full of fascinating information about the Periodic Table, the Pauli exclusion principle and just how these properties arise naturally from the fundamental nature of electrons.

I realise that this course is not for everyone. Be warned, the maths required is very different from that required for the Chemistry courses. You will need a very good grasp of solving partial differential equations and more than a basic capability in manipulating matrices, trigonometric identities, integration and differentiation. However, if like me, you enjoy maths (I took MST207 and that provided all the background required) and you find yourself yearning for a more in-depth treatment of some of the topics presented in the Chemistry units, then this course may just be the one for you.

Kathie Yeowell

### ChemSoc Diary

#### 4 May 2002

Guided tour of Cambridge Technology Museum. Cost £2. Meet at 10.30 am. Details from Janet Smith. jes39@student.open.ac.uk.

#### 22 June 2002

OU Open Day. Lectures, demonstrations, chemistry T-shirt logo design competition. Volunteers are needed to help with ChemSoc activities. If you are going and have some time to offer, contact one of the committee.

#### 14 September 2002

London Revision Day. Details from Pat Wilson.

#### 21 September 2002

Glasgow Revision Day. Details from Valerie Rutherford.

#### 27-29 September 2002

York Revision Weekend. Details from Carole Arnold.

#### 2-3 November 2002

AGM and Lecture Weekend. Great Barr Hotel, Birmingham. Details later.

#### February/March 2003

ChemSoc Weekend in Scarborough. Details later.

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### REVISION EVENTS 2002

#### **London: 14 September**

The programmes will comprise seminars, tutorials and problem-solving sessions for the courses: ST240, S205, S342 and S344 (subject to numbers). Approximate cost will be £40.

For course and location details only, send an SAE. To secure a place, please send a £10 non-returnable deposit\* together with your name, address 'phone and e-mail, student PI, OUCS membership number and **two** SAEs to:

**For the London Day: Pat Wilson, 106 Coronation Road, Bristol BS3 1AX**

**tel: 01179 664 544** : davebrava@aol.com

**For the Glasgow Day: Val Rutherford, 4 Wright Way, New Stevenson, Motherwell ML1 4LB**

**tel: 01698 832 295** : valerie@avrutherford.co.uk

#### **Glasgow: 21 September**

#### **York University Weekend 27-29 September**

The programme will comprise seminars, tutorials and problem-solving sessions for the courses: ST240, S204, S205, S216, S269, S207, S281, S327, S342, S344 and S381 (subject to numbers).

Cost £145 (standard), £170 (ensuite), (non-members £150/£175) covers teaching, accommodation and meals.

Send an SAE for details and booking form to:

**Carole Arnold, 51 Paddock Lane, Halifax, West Yorkshire HX2 0NT** : ca22@tutor.open.ac.uk

\* Cheques payable to Open University Chemistry Society